PREDICTING FIRE SPREAD IN ARIZONA'S OAK CHAPARRAL

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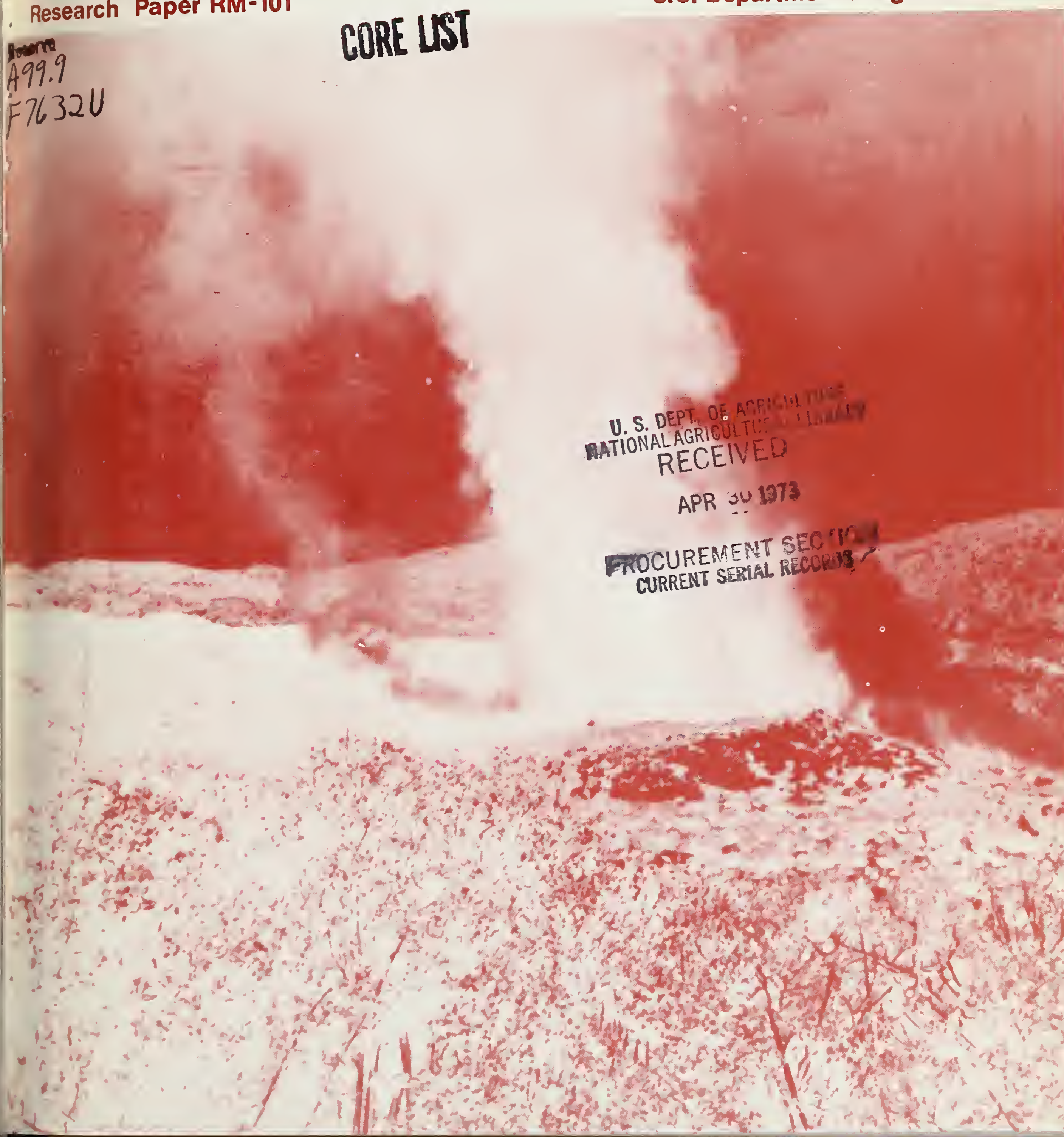

Abstract

Five existing fire models, both experimental and theoretical, did not adequately predict rate-of-spread (ROS) when tested on single- and multiclump fires in oak chaparral in Arizona. A statistical model developed using essentially the same input variables but weighted differently accounted for 81 percent of the variation in ROS. A chemical coefficient that accounts for effects of fuel chemistry on ROS is applied to the model. The model provides usable guidelines for predicting fire spread in Arizona oak chaparral.

Keywords: Arizona chaparral, fire spread, fire use, fuel chemistry.

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Contents

Predicting Fire Spread in Arizona's Oak Chaparral

A. W. Lindenmuth, Jr., and James R. Davis

Every person who has been involved with fire management is familiar with rate-of-spread (ROS)[2] indexes, meters, tables, models, and equations. More has been done and written about ROS than any other element of fire behavior, but none of the effort has applied specifically to oak chaparral in Arizona. The magnitude of fire behavior problems in the type is dramatically illustrated by the history of large and expensive-to-control wildfires, including the $2 million Battle fire in May 1972. This report summarizes and interprets the first research study of fire behavior in Arizona oak chaparral.

The study was concerned primarily with using fire as a tool for land managers. However, fire behavior is the same in both intentional and wildfires under the same conditions in oak chaparral.

Sections of this report deal with the study program, a description of the experimental area and research fires, a comparison of five contemporary ROS models with real-world research data, a new statistical model for predicting ROS, selection and use of fuel and weather variables, and discussion.

[2]*ROS in this report means forward movement of the fire head without spotting.*

Study Program

Research fires, ranging in size from single clumps of brush to ¼ acre were ignited in predominantly shrub live oak fuel (*Quercus turbinella* Greene). Of the 45 oak research fires ignited, 32 are suitable for analysis. The other 13 either went out or were rejected for technical reasons. Four larger evaluation fires were burned a year or more after the research fires to get comparison data for testing conclusions based on the smaller fires.

Experimental Area and Research Fires

Research fires were set on the Prescribed Fire Experimental Area, 30 miles east of Prescott on the Prescott National Forest, at an elevation of 4,750 feet (figs. 1, 2). Chaparral, or evergreen brush, covers about 8 percent of the total area of Arizona, or approximately 6 million acres. About

*Figure 1.--
Prescribed Fire Experimental Area, viewed from the north. Root-plowed firebreak surrounds entire area. Arrow indicates administrative site where laboratory, shop, and weather station are located.*

*Figure 2.--
Trailer provides field laboratory and office space, and houses recorders for long-term weather data. Metal shed provides workshop-storage space, and houses LP gas-fueled electric generators.*

85 percent is oak chaparral found normally at elevations from 4,000 to 5,500 feet. The largest block of oak chaparral surrounds the City of Prescott and the Experimental Area.

Average precipitation 1967-71, inclusive, was 16.05 inches; precipitation expected for Arizona oak chaparral is 13 to 16 inches (Nichol 1952). Average 1300-hour air temperature, all days, for June was 85° F. and for December 50° F.

The brush normally grows in clumps of some 10 to 30 feet in diameter. Fuels are fairly homogeneous within clumps, but change from clump to clump. Each clump is surrounded by a strip of virtually bare ground (fig. 3).

Polished stainless steel panels (each 4 feet by 10 feet) were erected around the sides of the research fires to control radiational and convective edge effects (fig. 3). An open passageway oriented with the wind allowed free movement of wind. The fire advanced on a straight line, edge-to-edge, as it normally would in a burning line of infinite length.

Each fire was ignited along the windward edge with a roll of excelsior (1 lb./lin. ft.) with electric squib-ignitor cord inserts at 3-foot intervals. After subsidence of the brief exaggerated flareup from massive ignition of both litter and crown, no trend toward either acceleration or deceleration was discernible.

All measurements were recorded electronically in an instrument trailer closeby. Measured variables that have been considered pertinent to ROS, from among more than 60 examined, are listed in table 1 with correlation coefficients, range, mean, and method of measurement.

Comparison of Contemporary Models with Research Data

These following five models fairly represent all research models conceived over the past 30 years to predict ROS. One of the important tasks of research is to test designed models under controlled conditions to determine how well they accomplish their objectives under a variety of conditions. We did this by measuring, on each research fire, the inputs required for each model and calculating predicted ROS. These were then compared statistically with actual ROS. We found that contemporary models are not suitable for predicting ROS under the fuel and climatic conditions prevailing in Arizona's oak chaparral.

The ROS model by Fons (1946) was derived experimentally by burning, in a wind tunnel, small constructed beds of (1) pine twigs set in a substrate like bristles in a brush, and (2) flat beds of pine needles. It treated spread as a series of ignitions of individual fuel particles. The model accounts for only 14 percent of the variation in ROS of the 32 research fires.

Byram's model (1959) was partly theoretical and partly empirical, based in some degree on longleaf and loblolly pine real-world research fires, in which Lindenmuth collaborated. It employed a relationship between flame length, available fuel, and heat of combustion of the available fuel. The model accounts for 48 percent of the variation in ROS, the best of any contemporary model, and performance can be improved appreciably by mathematical revisions.

Figure 3.--A typical research fire and area fuel distribution in oak chaparral on the Prescribed Fire Experimental Area, near Prescott, Arizona. Note the heat sink-thermocouple-radiation sensing package in the center of the burning line (feedout underground), heat flux transducer (horse), 35-mm camera and "midflame height" anemometer (right center), 16-mm time-lapse camera (on ladder), infrascope (on tripod), and power sprayer (to extinguish sample area at end of flaming combustion; lower left corner). Not shown are 36-foot tower (from which photo was taken) with another 16-mm time-lapse camera, and a 20-foot standard anemometer.

Table 1.--Summary of pertinent variables and correlations with measured rate-of-spread (ROS)

Description and variable	Unit of measure	Correlation coefficient[1]	Range in variable		Mean	Method of measurement
			Low	High		
Fuel consumed						
X_1 Flaming	lb./sq. ft.	0.45**	0.128	0.815	0.287	Representative stem sampling--percentage consumed by size classes
X_2 Total	lb./sq. ft.	.40*	.153	1.072	.407	
Fuel loading						
X_3 Total	lb./sq. ft.	.11	.229	1.597	.637	Representative stem sampling--mass by size classes/unit volume
	tons/acre		3.0	20.9	8.3	
Fuel moisture content						
X_4 Foliar	percent	.08	71.4	142.4	84.4	Random sampling--ovendrying
X_5 Litter, upper	percent	-.54**	4.3	17.9	8.1	
X_6 Litter, lower	percent	-.47**	5.4	26.5	10.9	
X_7 Dead stem	percent	-.59**	2.4	12.6	7.0	
Temperature						
X_8 Leaf	°F.	.43*	54	109	80	Thermocouples inserted in medium: air temperature in standard ventilated shelter--4.5 feet aboveground
X_9 Litter	°F.	.44*	48	115	79	
X_{10} Air	°F.	.44*	44	95	69	
Humidity						
X_{11} Relative humidity	percent	-.49**	7	67	21	Wet and dry bulb electro-aspirated psychrometer--standard ventilated shelter
X_{12} Saturation deficit	inches mercury	.42*	.098	1.438	.651	
Solar radiation						
X_{13} Net	ly/min.	.71**	.197	1.036	.741	Net radiometer
Wind velocity						
X_{14} At 20 ft. above canopy	m.p.h.	.34	4	19	8	Standard cup anemometer, low starting threshold
Fuel physics						
X_{15} Packing ratio		.20	.0019	.0123	.0047	Same as X_3
X_{16} Bulk density		.20	.0856	.5643	.2141	
X_{17} Surface area/volume ratio		.28	1259	2683	1742	
Fuel chemistry						
X_{18} Phosphates	percent	-.62**	.1740	.3913	.2917	Random sampling--quick frozen--freeze dried--standard lab analyses
X_{19} Potassium	percent	.14	.39	1.29	.62	
X_{20} Crude fat	percent	.31	3.0	6.9	4.9	
X_{21} Ash (silica not important)	percent	.34	3.3	10.9	6.3	

[1]Value must be $\geq$ .35 to be significant at 5 percent (*) level of probability and .45 at the 1 percent (**) level.

The problem with Byram's model is inputs. Inputs in a valid predicting model must be independent of the event to be predicted. Flame length and available fuel, which is the equivalent of fuel consumed, do not meet the requirement; they can only be measured during or after the fire for which ROS is to be predicted. The only alternative is to predict flame length and available fuel — in effect, resort to an inefficient and error-prone double prediction procedure to get to ROS.

Van Wagner's model (1967) is based on the concept that flame radiation is an important mechanism of heat transfer in the spread of fire. The principal components are flame length, weight of fuel, radiation intensity emitted by flame, proportion of radiation absorbed by fuel, fuel moisture, and angle between flame and fuel bed. The model accounts for 36 percent of the variation in the research data. Several components are dependent on the fires.

Rothermel's model (1972) follows the concept that ROS is proportional to the ratio of energy output to energy required to heat fuel to the ignition temperature. It is based in part on small laboratory fires. Fuel characteristics are heavily weighted. The latest version includes a variable moisture of extinction which does not work in Arizona oak chaparral. An earlier version with a constant moisture of extinction

accounts for only 12 percent of the variation in the research data.

The National Fire-Danger Rating model[3] is a modification of the Rothermel model; some fuel inputs are held constant, windspeed is calculated from velocity measured at 20 feet, and fuel loading is separated into "timelag" classes. This model accounts for 21 percent of the variation in the research data — the best performance of the models tested that do not include fire-dependent inputs.

A rate-of-spread model derived experimentally from relatively local situations will almost invariably outperform a similar model developed elsewhere or a broadly based theoretical model. This study has shown that to be the case in Arizona chaparral.

A theoretical model is used in the National Fire-Danger Rating System as a basis for the ROS prediction (Deeming et al. 1972). This and other predictions are transformed to dimensionless indexes because a relative measure is all that is required. Therefore, for the purposes of fire-danger rating, absolute errors are of no consequence as long as the relative changes are predicted so the performance is considered adequate. Fuel-type differences are described by fuel models which tailor the inputs to broad type classifications.

Both types of models have their places. A fire-use manager desiring more quantitative than relative predictions will have to rely for now on the somewhat narrower statistical models. Quite likely the data from empirical study will be useful in making the inputs for theoretical models more accurate, but there will always be a trade-off between definitive local applications and broad relative applications.

New Statistical Model

The statistical model was derived by correlation and regression analyses directly from the 32 research fires. Following are two versions (see table 1 for identity of X's; c.c.= chemical coefficient). The versions are essentially the same and account for 79 percent and 81 percent, respectively, of the variation in the ROS data, but inputs are handled differently.

Version 1:

$$Y = \left\{9.97 - 0.0399X_4 + 0.0586X_{10} - 0.1213X_{11} + 6.483X_{13} + 0.3010X_{14}\right\}\left\{c.c.\right\}$$

Measurements of air temperature (X_{10}), relative humidity (X_{11}), and net radiation (X_{13}) must be transformed (table 2). Because the contributions of these variables appear nonlinear, version one alternative is to transform the variables and keep the model linear.

Table 2.--Transformation of variables for use in version 1 of new statistical model

Air temperature (°F.)		Relative humidity (%)		Net radiation (ly/min.)	
Measured	Transformed	Measured	Transformed	Measured	Transformed
40	20.0	4	4.5	0.45	0.43
45	23.5	8	5.0	.50	.51
50	28.5	12	6.5	.55	.58
55	36.0	16	12.0	.60	.65
60	46.0	20	20.5	.65	.72
65	61.0	24	30.0	.70	.78
70	83.0	28	38.0	.75	.83
75	94.5	32	42.5	.80	.87
80	98.0	36	45.5	.85	.91
85	99.0	40	48.0	.90	.94
90	99.1	45	50.0	.95	.95
95	99.5	50	52.0	1.00	.96
100	99.8	55	53.0	1.05	.96
110	100.0	60	54.0	1.10	.96

Version 2:

$$Y = \left\{26.1657 - 0.0335X_4 - 24.5608\exp\left[-0.06\,(X_{10}/X_{11})\right] + 14.1760X_{13} - 3.1394X_{13}^2 + 0.3526X_{14}\right\}\left\{c.c.\right\}$$

$$c.c. = \left\{1 - 5.1196\left[1 - \exp\,(X_{18} - 0.235)\right]^{.39}\right\}$$

Version 2 alternative is to build the transformations into the model and enter the model with directly measured values. Air temperature (X_{10}) and relative humidity (X_{11}) are combined into a single interaction term. The data suggest

[3]*Schroeder, Mark J., Michael A. Fosberg, James W. Lancaster, John F. Deeming, and R. William Furman. Technical development of the National Fire-Danger Rating System. (Unpublished report, dated Feb. 1972, on file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

nonlinearity in some of the variables, and it is reasonable to expect an interaction between these closely correlated variables. This version of the model appears somewhat more efficient than the other.

Chemical Coefficient (c.c.)

The chemical coefficient brings in the effect of fuel chemistry on ROS. This effect is discussed under "Selection and Use of Variables." The mathematical expression for the chemical coefficient is shown separately because fire managers are not expected to sample foliage and run analyses for phosphate content. Tabulated values are used instead (table 3). These are representative values based on a large number of chronologic samples.

Table 3.--Multiplying factor to correct ROS estimate for foliar phosphorus content under three conditions[1]

Month	Condition 1	Condition 2	Condition 3
March	1.0	2.2	2.2
April	1.0	1.6	1.6 (early)
			1.0 (late)
May	1.0	1.6	1.0 (early)
			1.6 (late)
June	1.0	1.7	1.7
July	1.6	1.6	1.0
August	1.7	1.0	1.0
September	1.0	1.0	1.0
October	1.0	1.0	1.0
November	1.0	1.0	1.0
December	1.0	1.0	1.0
January	1.0	1.7	1.7
February	1.0	1.8	1.8

[1]Condition 1: $\geq$ 3.00 inches precipitation preceding December + January; continue this column for 12 months, starting with March.

Condition 2: $\leq$ 3.00 inches precipitation preceding December + January; precipitation February + March < 3.00 inches; shift to condition 3 if February-March precipitation $\geq$ 3.00 inches.

Condition 3: < 3.00 inches precipitation preceding December + January; precipitation February + March $\geq$ 3.00 inches.

Model Restrictions

Litter and dead twigs ¼ inch or less in diameter must be reasonably dry for reliable predictions; 15 percent and less is satisfactory. Actual measurements are not necessary; variations in actual moisture content between 5 and 10 percent, the normal range during precipitation-free periods, have relatively little effect on ROS. Ordinarily this range of dryness will be reached within 5 consecutive days of clear seasonally warm weather April through October, and within 10 days during the remainder of the year.

Selection and Use of Variables

Variables were selected on a physical basis in order to cover a wide range of conditions. One form of each of the following variables was wanted: fuel moisture, temperature, humidity, wind velocity, solar radiation, fuel physics, and fuel chemistry. Another consideration was convenience in acquiring reliable data.

Slope was intentionally eliminated from the study by locating all plots on level or practically level ground. The interactions involved between slope and wind are complex and as yet unsolved. An attempt to solve this interaction would have added too much complexity to this initial study.

Fuel Moisture Content (X_4, X_5, X_6, X_7)

All ROS versus dead fuel moisture correlations (X_5, X_6, X_7) are highly significant. Any one could be used in a predicting model, but foliar moisture (X_4), although not significant in simple regression, is significant when included in multiple regression with weather variables to account for variation in ROS. Dead fuel moisture variables are also highly correlated with temperature, humidity, and net solar radiation; therefore, when a dead fuel moisture variable is introduced with these variables, it does not account for any significant reduction in residual variance. Dead fuel moisture alone cannot replace the weather variables, however.

Foliar moisture was selected over dead fuel moisture, but the latter must be retained in some form because of its limiting characteristics. Dead fuels do not burn vigorously, above 15 percent actual average moisture content, and normally cease to burn at approximately 25 to 30 percent. It is not feasible, due to interactions between variables, to build these limitations into the model now. Dead fuel moisture is retained as an external independent limiting factor.

Moisture content from a representative sample of leaves is needed for accurate predictions. Samples are thoroughly dried, but

without scorching, at 217° F. Moisture content is calculated as follows:

$$\left(\frac{\text{fresh weight - dry weight}}{\text{dry weight}}\right) 100$$

In the absence of actual data, ROS can be approximated roughly by using the appropriate representative moisture content (table 4).

Table 4.--Representative foliar moisture values for approximating ROS under three conditions[1]

Month	Condition 1	Condition 2	Condition 3
	- - - - - - *Percent* - - - - - - - -		
March	79	79	79
April	82	76	81
May	134	[2]74	82
June	96	[3]73	89
July	86	70	79
August	86	105	93
September	81	99	88
October	80	89	84
November	81	88	81
December	81	86	81
January	77	85	77
February	78	84	78

[1]Condition 1: ≥ 3.00 inches precipitation preceding December + January. Continue this for 12 months starting with March.

Condition 2: < 3.00 inches precipitation preceding December + January. Precipitation February + March < 3.00 inches. Shift to Condition 3 if February-March precipitation ≥ 3.00 inches.

Condition 3: < 3.00 inches precipitation preceding December + January. Precipitation February + March ≥ 3.00 inches.

[2]Considerable die-off of leaves is probable, thereby increasing flammability temporarily.

[3]Considerable shedding of leaves is probable, thereby decreasing flammability until new leaves harden in September or October.

Temperature (X_8, X_9, X_{10})

ROS is significantly correlated with leaf, litter, and air temperatures; each is important in the model. Air temperature is used for convenience, and measured 4½ feet aboveground in a standard ventilated shelter.

Humidity (X_{11}, X_{12})

Either relative humidity or saturation deficit should be included in the models. The former is selected for convenience and is measured in the same position as temperature.

Solar Radiation (X_{13})

Radiation, direct and indirect, flows to and from fuel at all times; the fraction retained by fuel at a particular instant is net radiation (langleys/minute). Because ROS is significantly correlated with net radiation, net radiation is important in the model.

Actual measured values at the site just prior to ignition are needed for accurate predictions. A net radiometer is exposed so the top face "sees" the sun and the bottom face "sees" the fuel. The radiometer generates a small electrical output proportional to the difference in temperature between the two faces. The output is measured with a millivolt meter, and converted to langleys/minute by means of a calibration chart.

In the absence of actual measured data, representative net radiation values (fig. 2) can be used to approximate ROS.

Wind Velocity (X_{14})

Average 20-foot velocity, above average vegetation crown profile, is the only expression of wind that needs to be included from among nine alternatives examined, including independent measurements at 4 feet aboveground and frequency of wind gusts.

Wind velocity does not show the strong effects on ROS usually attributed to it. An explanation is in order, based on case histories.

The fastest spreading research fire (46.25 feet per minute or 0.53 m.p.h., without spotting) *burned with average wind of 7 m.p.h.,* air temperature 95° F., relative humidity 15 percent, and litter moisture 4.5 percent (fig. 4). There was no opportunity to test higher wind velocities in other fires with conditions otherwise the same.

The *highest average wind velocity* for a research fire was *19 m.p.h.* with air temperature 76° F., relative humidity 16 percent, and litter moisture 6.6 percent. ROS was 31.54 feet per minute or 0.36 m.p.h., without spotting (fig. 5).

Wind velocity during the second fire was almost three times higher than in the first, yet ROS was only about two-thirds that in the first. Except for air temperature other variables were similar in both fires. This comparison illustrates the less-than-dominant influence of wind measured throughout the research fires.

Figure 4.--Although this was fastest spreading research fire, the flames (outlined for clarity) are standing up, in keeping with the relatively low windspeed.

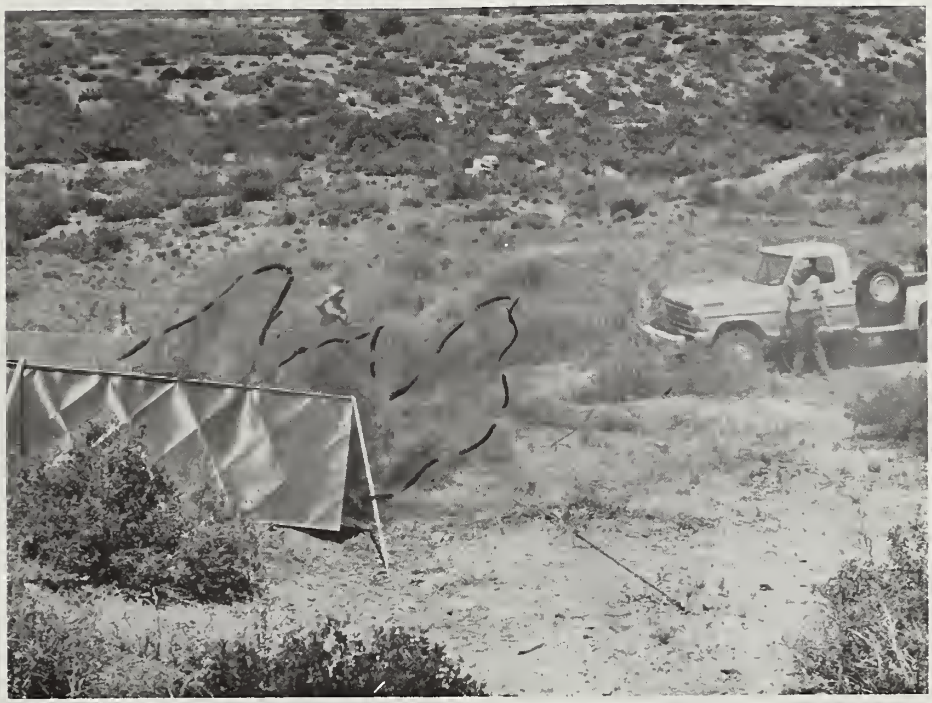

Figure 5.--Flames are lying over, blown by relatively high wind, nearly three times as fast as in figure 4. However, rate-of-spread was only two-thirds that of faster fire.

What does the record show about wind? Briefly:

1. Wind is a limiting factor; a velocity of at least 7 to 8 m.p.h. is needed for fuel to burn well during favorable temperature and moisture conditions.
2. Wind is a provisional factor; increasing wind increases ROS *provided* temperature and moisture conditions are favorable for burning and do not regress.
3. When wind increases ROS without spotting, the increase is linear and amounts to about 4 inches per minute or 20 feet per hour for each additional m.p.h. in wind velocity. When spotting occurs, the ROS increases more rapidly, perhaps curvilinearly, with increasing windspeed.
4. During flaming, wind does not boost the percentage of fuel consumed appreciably, if any ($r = 0.04$, $b = 0.0044$). ROS and fuel consumed are closely correlated. Hence, failure of increasing wind to increase fuel consumed apparently is one reason why the effect of wind is limited in Arizona oak chaparral.

The 4-inch-per-minute increase in ROS for each additional m.p.h. in wind velocity (20 feet) is in line with recently published results from an independent study of ROS in slash fuels (Brown 1972).

Fuel Physics

(X_1, X_2, X_3, X_{15}, X_{16}, X_{17})

ROS is significantly correlated with fuel consumed, which is the equivalent of available fuel (X_1, X_2). Available fuel can be estimated reliably if fuel loading is accurately known, but a feasible estimating model for the latter is not yet ready. The correlation is not built into the model at this time.

Packing ratio (ratio of fuel volume to fuel bed volume, X_{15}), bulk density (ratio of fuel weight to volume, X_{16}), and surface area to volume ratio (X_{17}) apparently affect ROS. Effects were analyzed by fuel size components and for total fuel. None of these contributed appreciably in the multivariate analysis.

Within the range of fuel conditions among the research fires, the model works satisfactorily without fuel physics variables. Whether these variables will be needed for satisfactory operation throughout the entire oak chaparral type can be answered accurately only by experimentation over a broader range of fuel conditions.

Fuel Chemistry

(X_{18}, X_{19}, X_{20}, X_{21})

Content of phosphate phosphorus affects ROS appreciably, according to results from both these research fires and supporting laboratory burning tests. There is a critical threshold at 0.235 percent; with decreasing PO_4 below that level ROS increases, with increased PO_4 above the threshold there is no change in ROS. This pattern is built into the model as a coefficient or multiplier.

A model for predicting phosphate content is under development. Pending its availability, representative values (table 3) can be used for approximating ROS. It is not feasible now, or within the foreseeable future, to make chemical analyses part of fire management operations.

Crude fat and ash (both total and silica free) appeared to affect ROS of research fires, but these indications were not confirmed by laboratory burning tests. The sign of the ash correlation, although nonsignificant, is opposite to that found elsewhere (Rothermel 1972). For these reasons crude fat and ash are not in the model.

Discussion

The new statistical model is not perfect, but it is the most accurate and reliable operational predictor of fire behavior for the Arizona oak chaparral type. The variables used are about the same as in contemporary models; the change is essentially in weighting.

Contemporary models that give heavy weight to wind velocity, dead fuel moisture, and fine fuel moisture (composite of cured and green herbaceous material) predict an ROS that is too high for the cool half of the year (November-April) and too low for the warm half (May-October) in Arizona oak chaparral. Briefly, the reasons are that wind velocity, humidity, and dead fuel moisture (estimated by contemporary methods, which also are based primarily on relative humidity) are practically the same in both halves of the year. Relative humidities below 15 percent (1300 hour), for example, are common in both cool and warm months, which may surprise people not familiar with Arizona. ROS predictions based on wind and dead fuel moisture only, for precipitation-free periods, average about the same year-round. Because fine fuel moisture is notably higher in the warm half of the year (warm-weather growers predominate), inclusion of this variable appreciably lowers ROS predictions in the warm

half of the year. By comparison, fires burn much more vigorously and spread faster in the warm half, contrary to predictions based on wind, fuel moisture, and herbaceous condition.

The new statistical model corrects this significant anomaly by heavily weighting net radiation and air temperature, both of which have marked seasonal trends (figs. 6, 7). These variables also account for important day-to-day variations (note the range of these variables within months).

Predictions with the new statistical model were compared with actual ROS of four quarter-acre evaluation fires. Spread both within clumps and between a number of clumps across breaks of varying widths was measured. This small sample indicates that fires in broken, discontinuous fuel spread about 5 percent slower, on an average, than in continuous, relatively homogeneous fuel. Deviations of predicted from actual ROS were -1 percent, zero, +5 percent, and +18 percent. To better appreciate the significance of these deviations, it is worth noting that a test of another ROS model by Brown (1972) with small manmade slash plots showed deviations of predicted from actual of -14 to 580 percent, which he considered "reasonably close agreement."

How can the statistical ROS predictions be interpreted in fire management? Key ROS numbers are 10, 20, and 40, for level or slightly sloping areas. When predicted ROS is less than 10 (approximately), fuel probably will not burn well. Fire set repeatedly may spread through the litter and consume some aerial fuel, but it normally will not crown continuously through an individual clump or spread from clump to clump. Between 10 and 20 (approximately), individually ignited clumps probably will burn reasonably well, but fire normally will not spread from clump to clump continuously. Above 20, fire normally will spread from clump to clump continuously, and up to 40 will burn steadily, but not explosively. Above 40 (approximately), fire

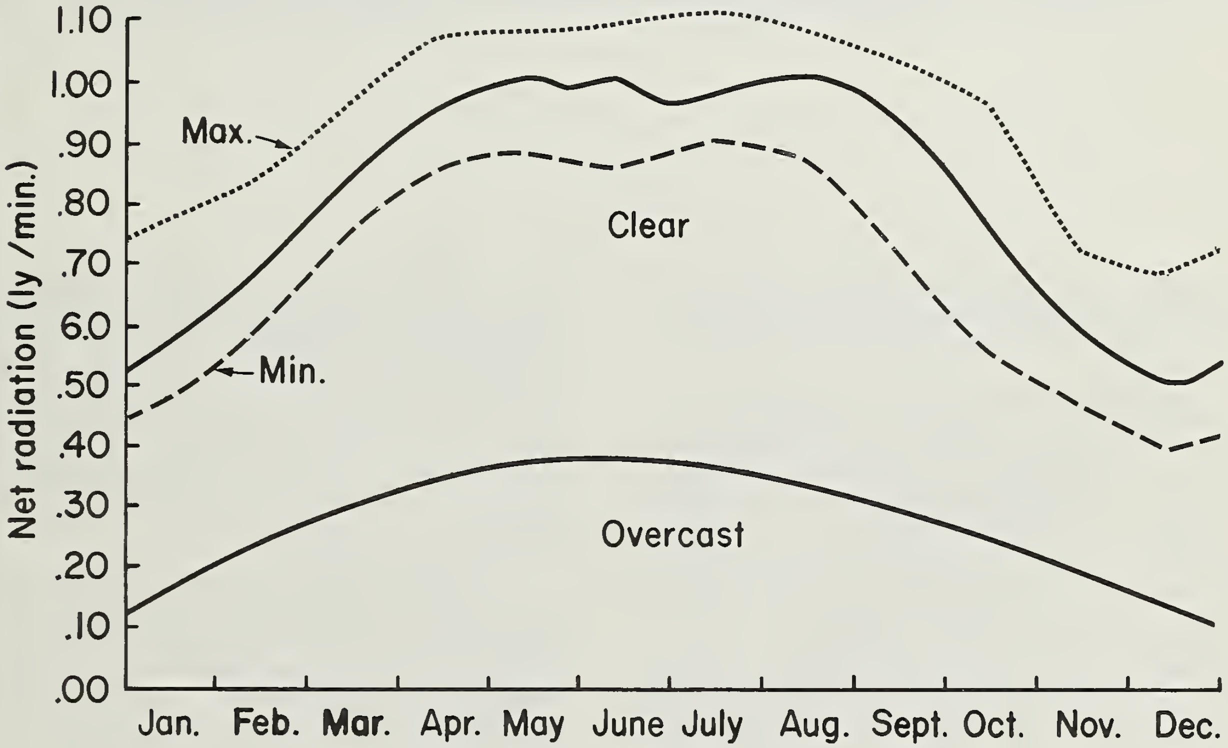

Figure 6.--Summarized net radiation values at 1300 hours for 1968-71, inclusive, at the Prescribed Fire Experimental Area may be used for approximating ROS. The atmosphere is relatively pollution-free over the Experimental Area; near sources of significant pollution, net radiation would be lower. The aberrations in the May-June period apparently result from atmospheric haze associated with drought and turbulence.

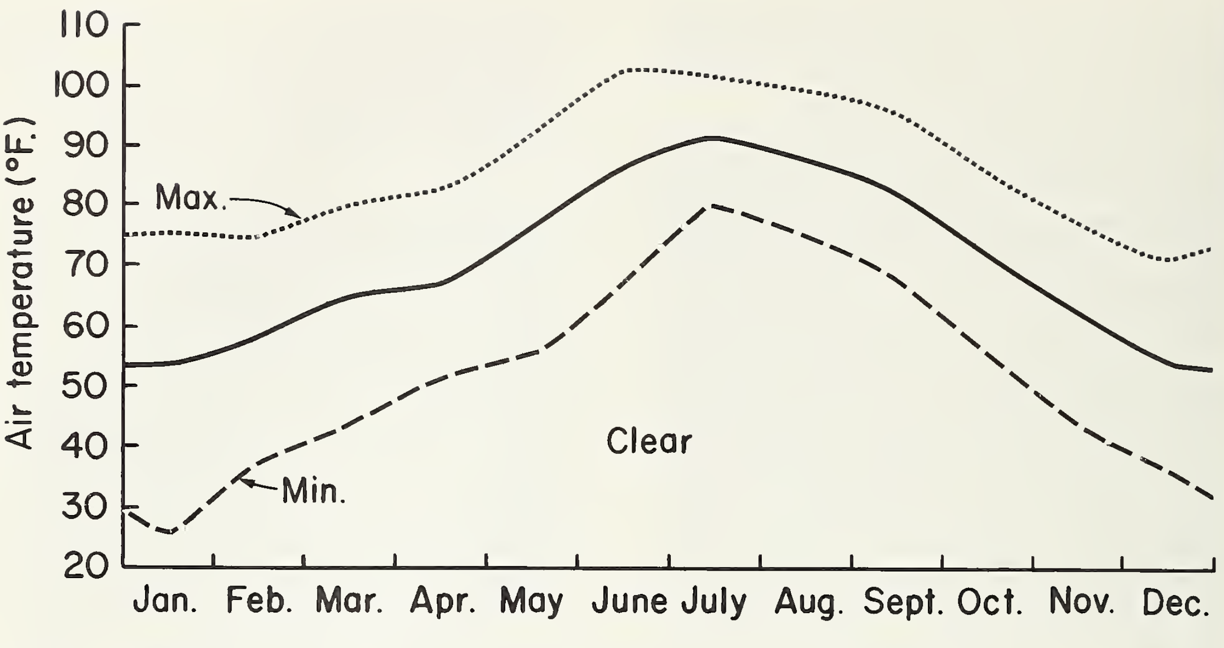

Figure 7.--Summarized air temperature values at 1300 hours for 1968-71, inclusive, at the Prescribed Fir Experimental Area may be used for approximating ROS in the absence of actual measurements.

probably will be flashy, normally too much so for prescribed burning. The key numbers must be adjusted downward where slope and/or spotting are factors.

People experienced in Arizona oak chaparral have always maintained that chaparral either burns fiercely or does not burn at all — no gradation in between. This rule of thumb is relatively accurate. The critical ROS threshold is around 20 feet per minute; conditions must be suitable for generating spread at or above that level before fire will spread across country. Thus the minimum sustained spread (without spotting) ever seen, usually in intentional fire, is about one-quarter mile per hour, and in wildfires normally one-half mile per hour or higher, because wildfires tend to occur during some of the worst conditions and commonly include spotting.

A 28,400-acre wildfire, May 14-20, 1972, on the Prescott National Forest provided an operational check of the statistical model and interpretations. The initial ROS, from 1215 to 1500 hours in a mixture of oak and manzanita chaparral, was scaled at 45 feet per minute, 1.25 feet per minute less than the fastest spreading research fire. The wildfire included some short-range spotting and a variety of slopes and fuel conditions. Predicted ROS was 40 feet per minute (based on data from tables 3 and 4, fig. 6) and measured temperature, relative humidity, and wind. The 11 percent deviation probably is attributable to spotting, favorable slope-wind interaction during part of the run, and the admixture of manzanita. This fire was unquestionably flashy.

The type of fire that does not spread from clump to clump is potentially quite useful in land management. It can be used to burn firebreaks and small areas safely without bulldozing, brush smashing, and other special measures heretofore employed in intentional burning, at considerable cost both in dollars and site disturbance. Forming fuelbreaks by nonspreading fire is feasible, economical, and effective, although additional research is needed to work out operational details. When designed to dissect large areas of chaparral, these breaks can substantially lessen the probability of large, catastrophic wildfires.

Fire managers must know more about fire behavior than ROS in order to use fire efficiently, however. Degree of fuel consumption, fire intensity, and level of byproduct emissions are other considerations.

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Five existing fire models, both experimental and theoretical, did not adequately predict rate-of-spread (ROS) when tested on single- and multiclump fires in oak chaparral in Arizona. A statistical model developed using essentially the same input variables but weighted differently accounted for 81 percent of the variation in ROS. A chemical coefficient that accounts for effects of fuel chemistry on ROS is applied to the model. The model provides usable guidelines for predicting fire spread in Arizona oak chaparral.

Keywords: Arizona chaparral, fire spread, fire use, fuel chemistry.

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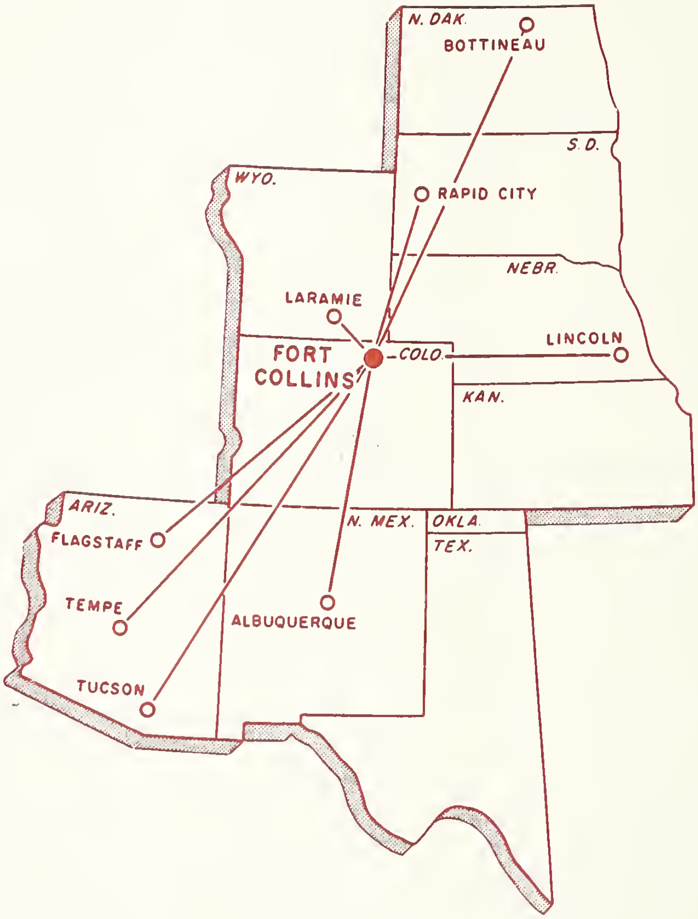

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